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Kessler et al.

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(54) **TISSUE-REMOVING CATHETER INCLUDING ANGULAR DISPLACEMENT SENSOR**

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(51) **Int. Cl.**

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A61B 17/00	(2006.01)

(52) **U.S. Cl.**

CPC ***A61B 17/320758*** (2013.01); *A61B 17/3207* (2013.01); *A61B 2017/00017* (2013.01); *A61B 2017/320741* (2013.01); *A61B 2017/320791* (2013.01)

(58) **Field of Classification Search**

CPC A61B 17/32; A61B 17/320758; A61B 2017/2927; A61B 17/320016; A61B 17/32002; A61B 17/3207; A61B 17/320708; A61B 17/320725; A61B 17/32075; A61B 17/320783; A61B 2017/32004; A61B 2017/32008; A61B 2017/320716; A61B 2017/320733; A61B 2017/320741; A61B 2017/320791

See application file for complete search history.

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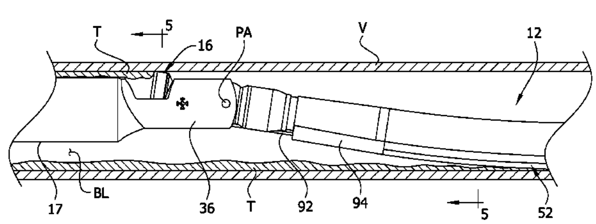
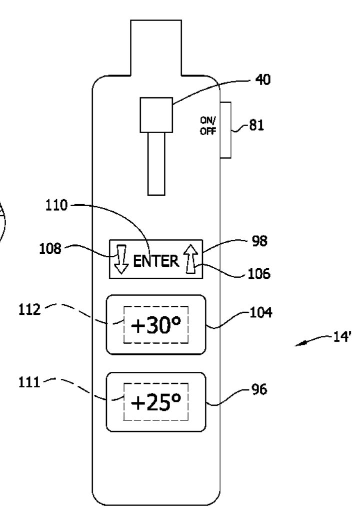
Primary Examiner — Jonathan Miles
Assistant Examiner — Kankindi Rwego

(57) **ABSTRACT**

A tissue-removing catheter for removing tissue from a body lumen includes a tissue-removing element. The tissue-removing element may be coupled to a first longitudinal portion of the catheter body. An angular-displacement sensor may be coupled to the catheter body for detecting an angular displacement of at least the first longitudinal portion of the catheter body relative to the rotational axis when the first longitudinal body portion is rotated about the rotational axis. The tissue-removing element may be rotatable about a rotational axis to adjust an angular tissue-removing position of the tissue-removing element relative to the body lumen when the catheter body is inserted in the body lumen. An angular-displacement sensor may be generally adjacent the tissue-removing element for detecting an angular displacement of the tissue-removing element relative to the body lumen when the tissue-removing element is rotated about the rotational axis.

15 Claims, 17 Drawing Sheets





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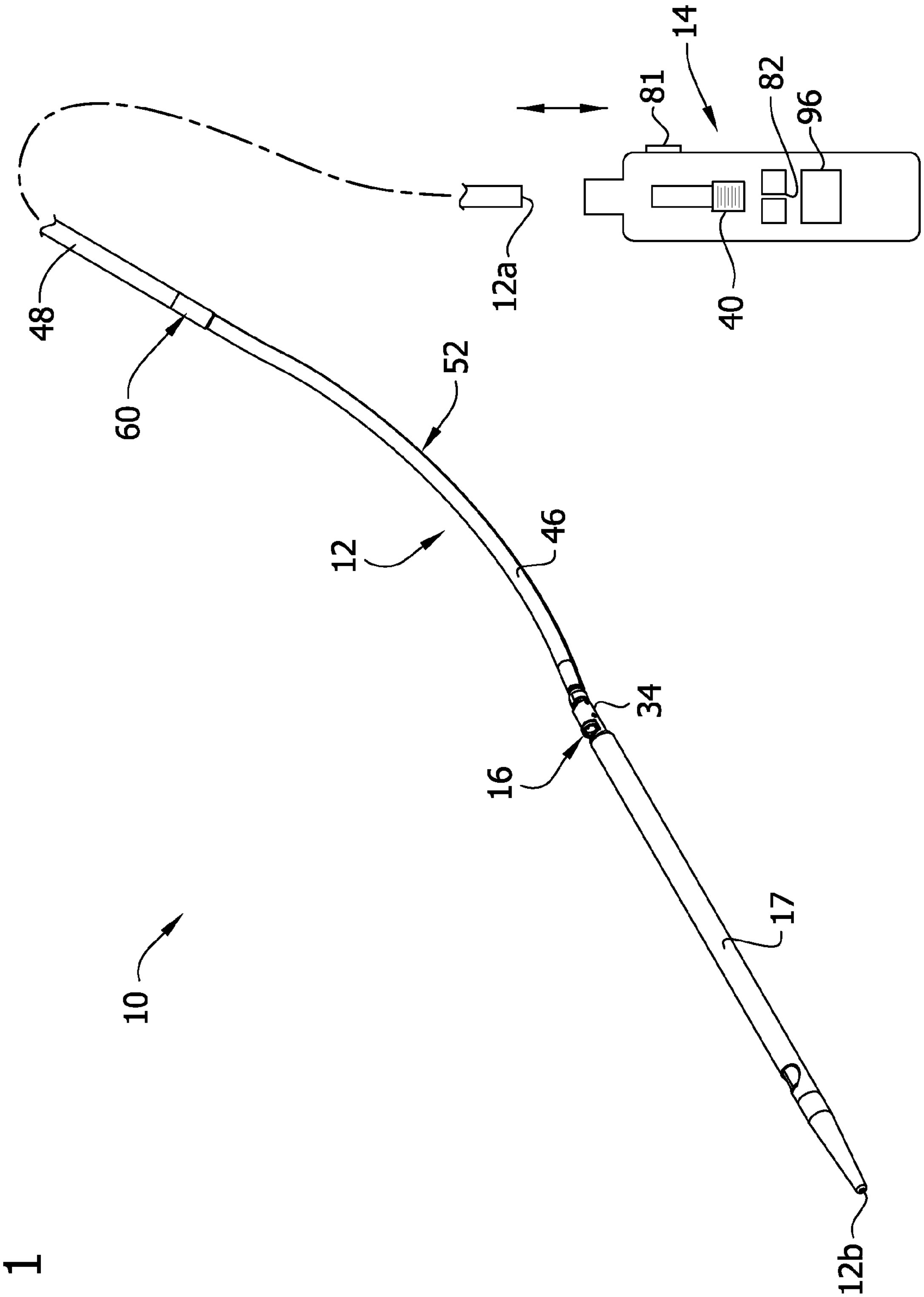

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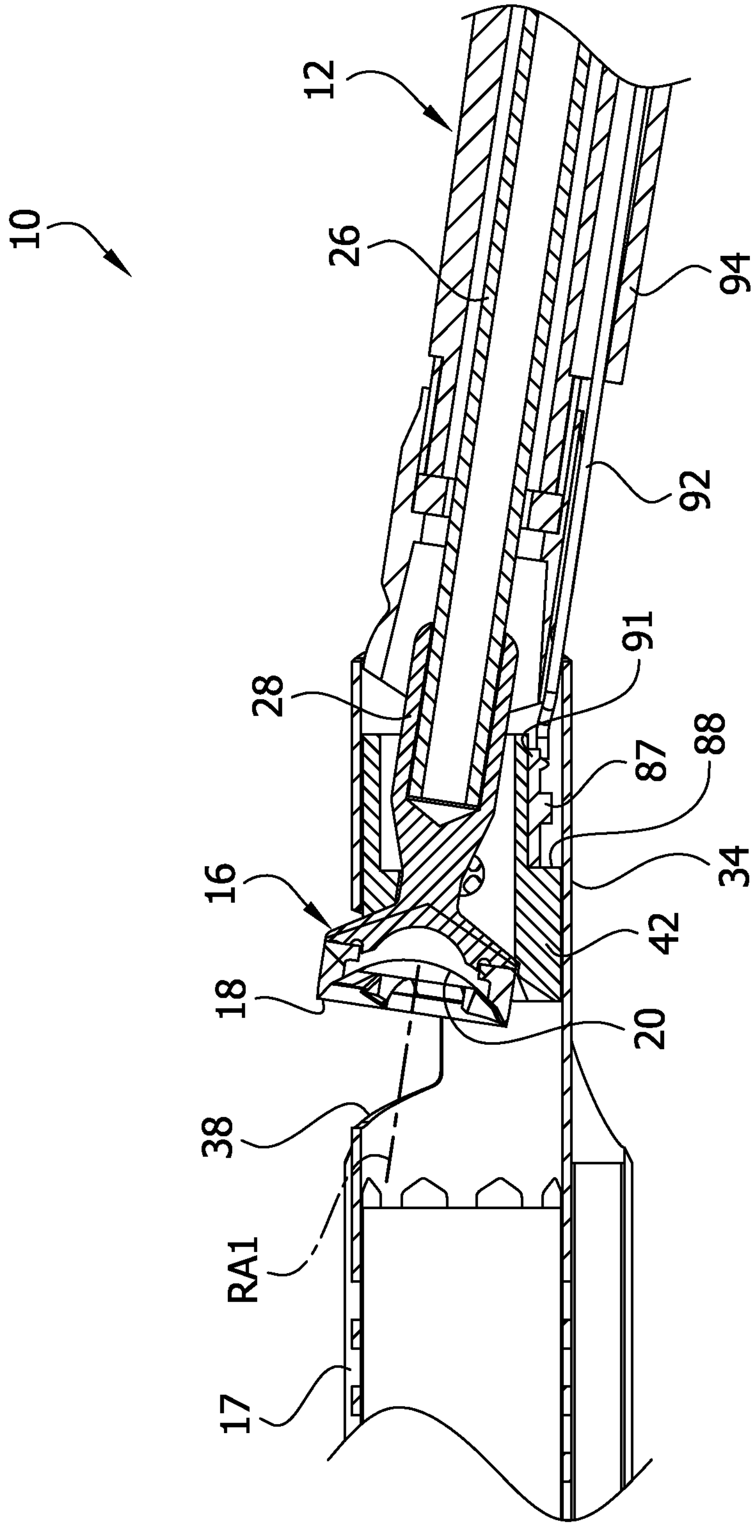

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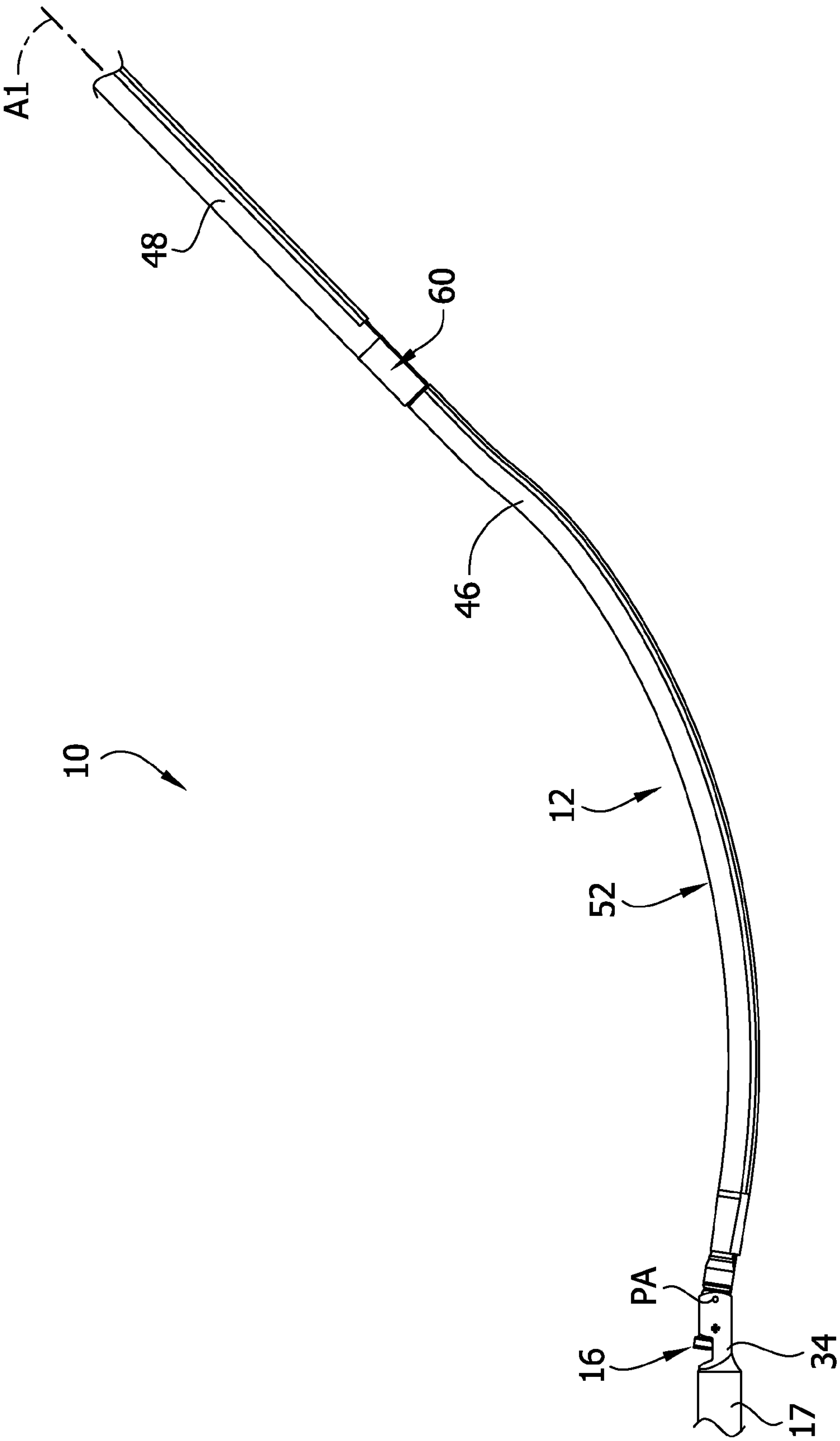

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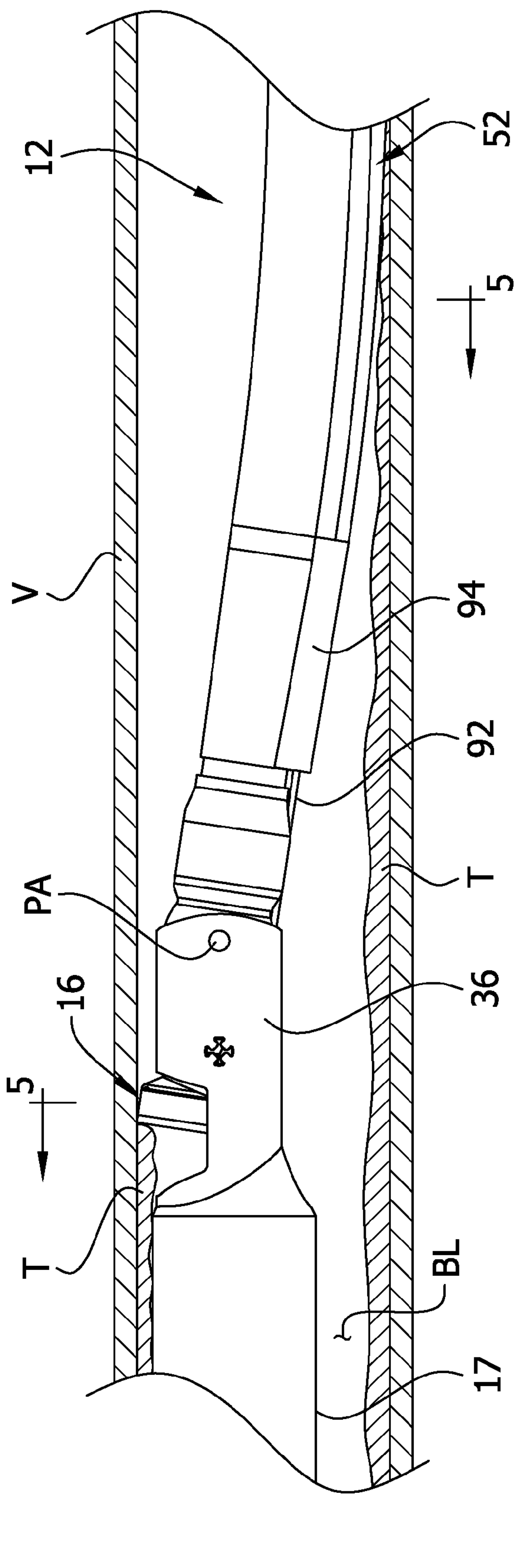
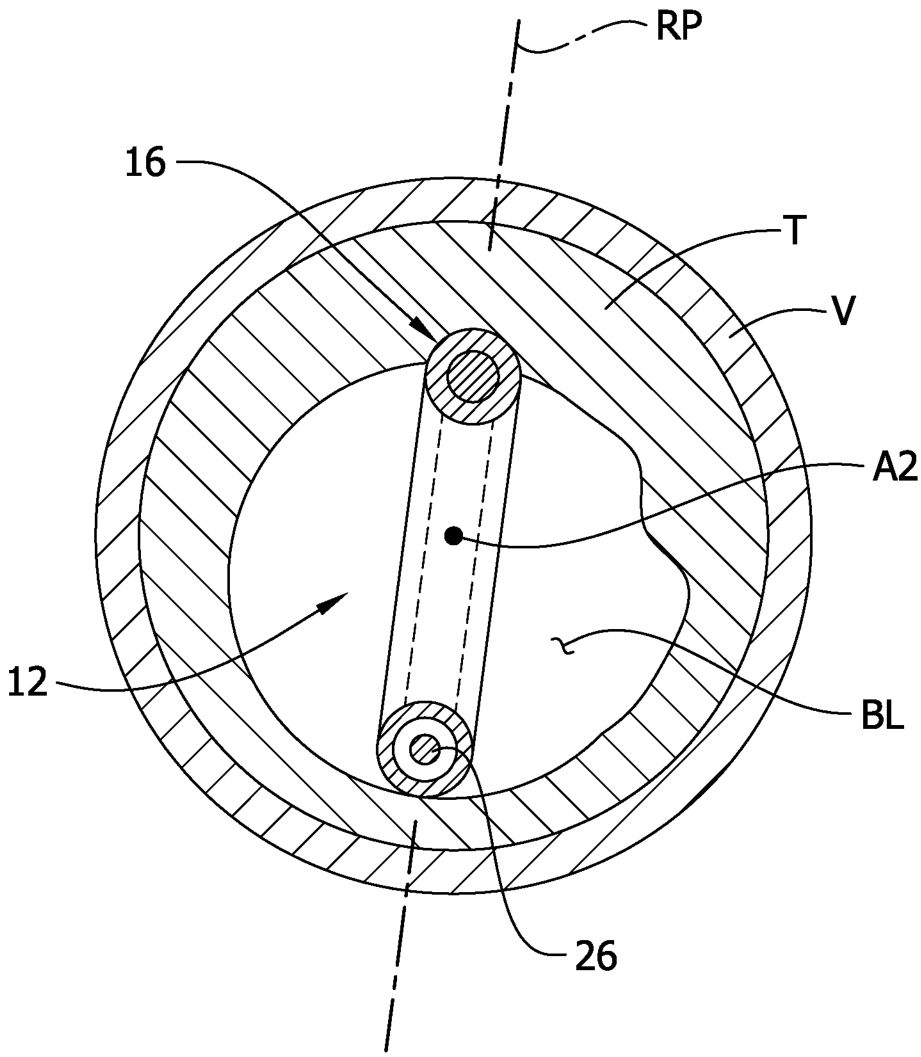


FIG. 4

FIG. 5



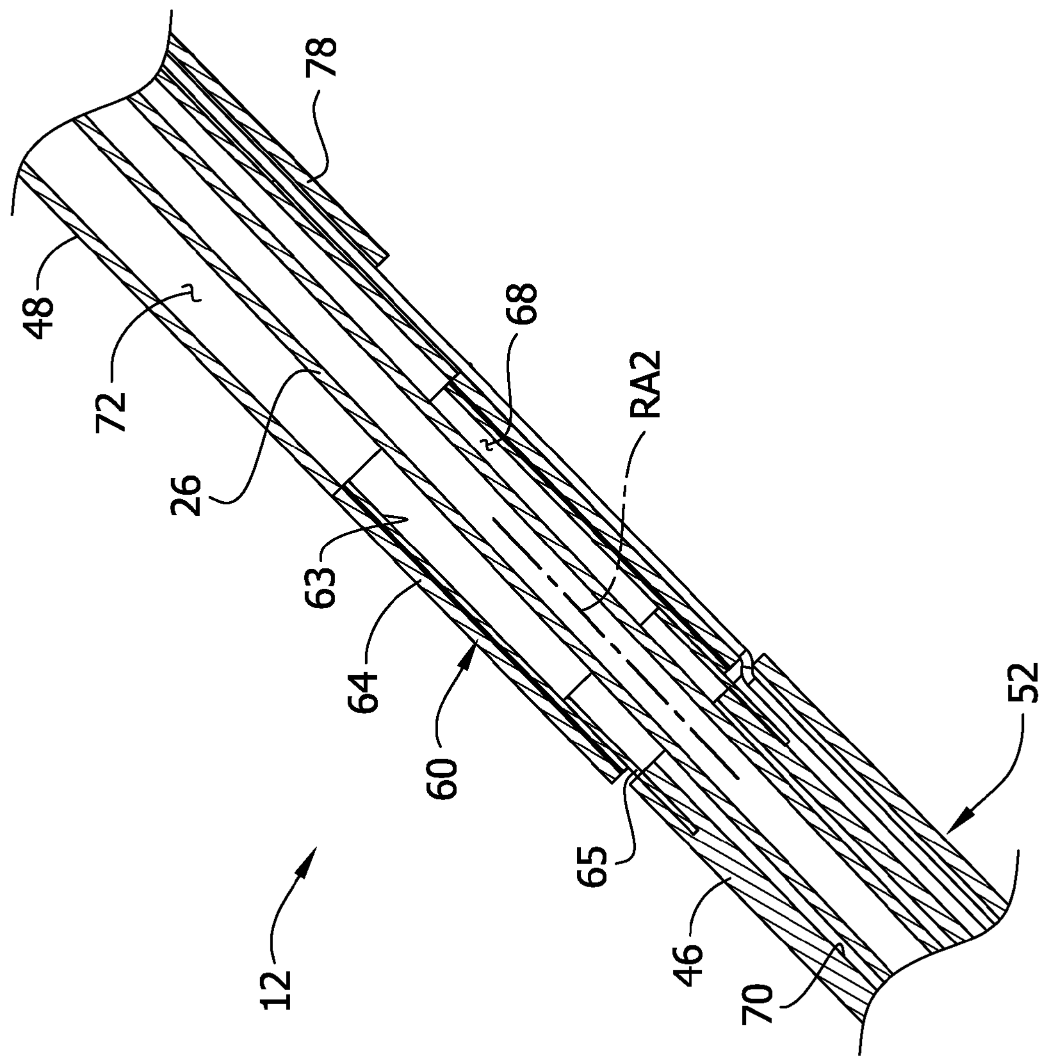
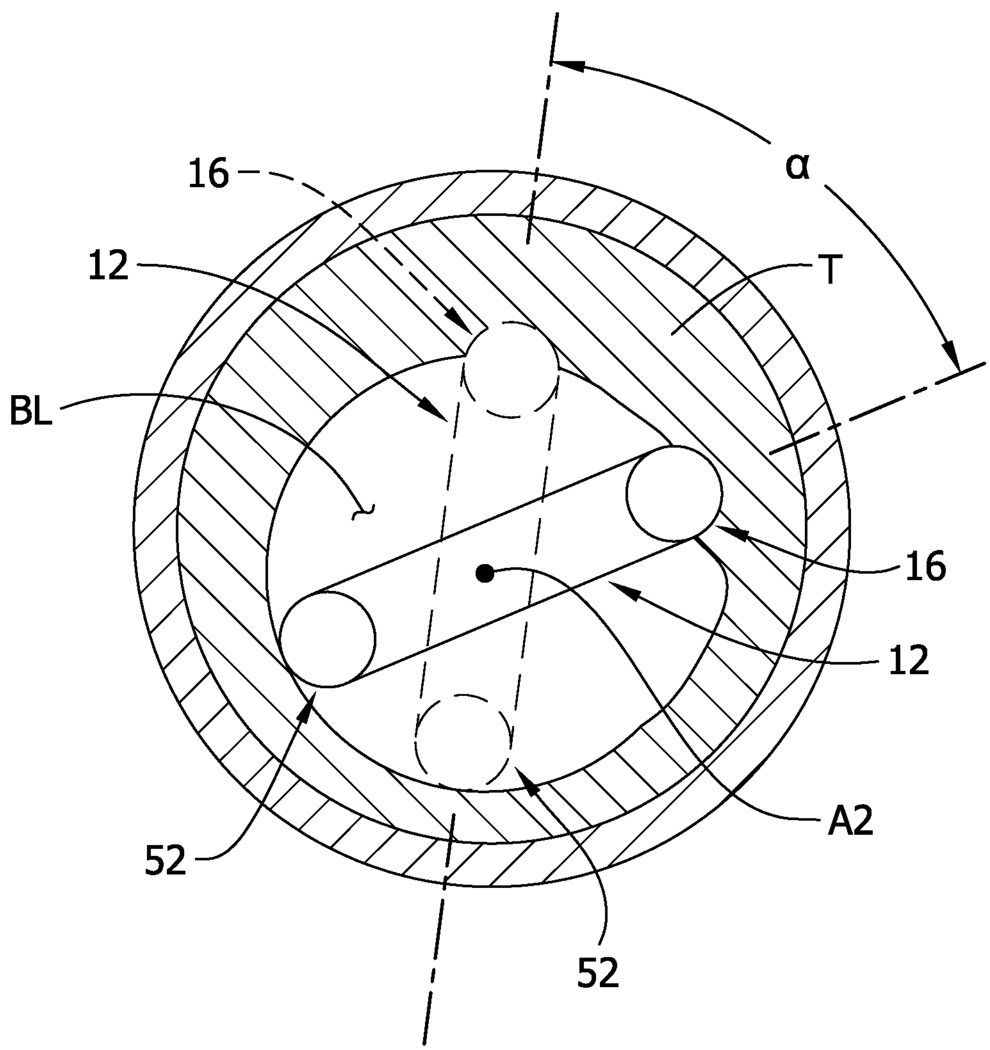
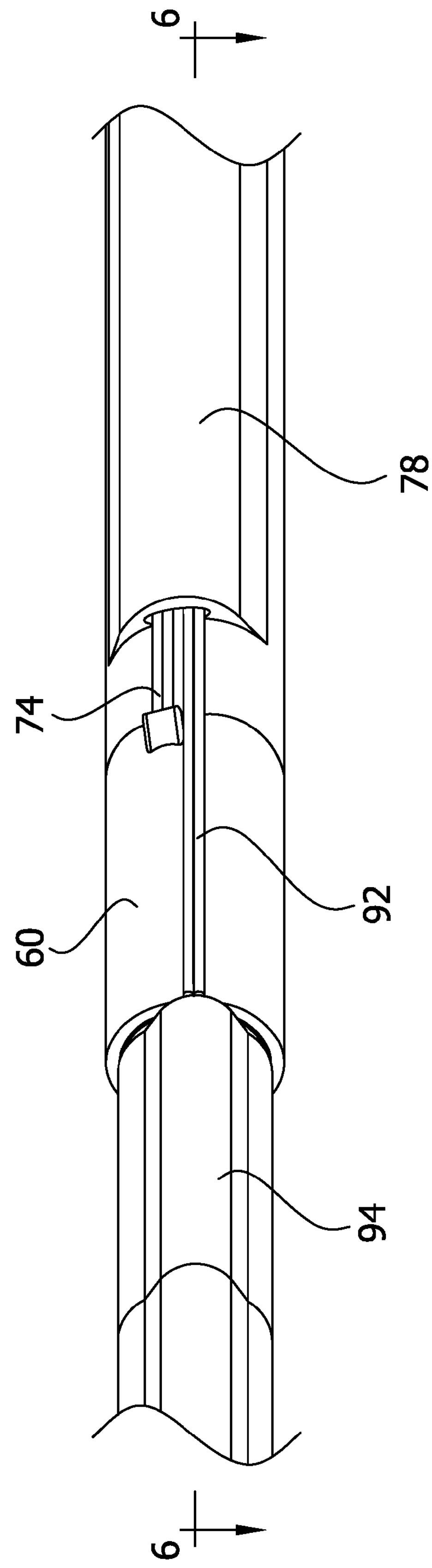


FIG. 6

FIG. 7





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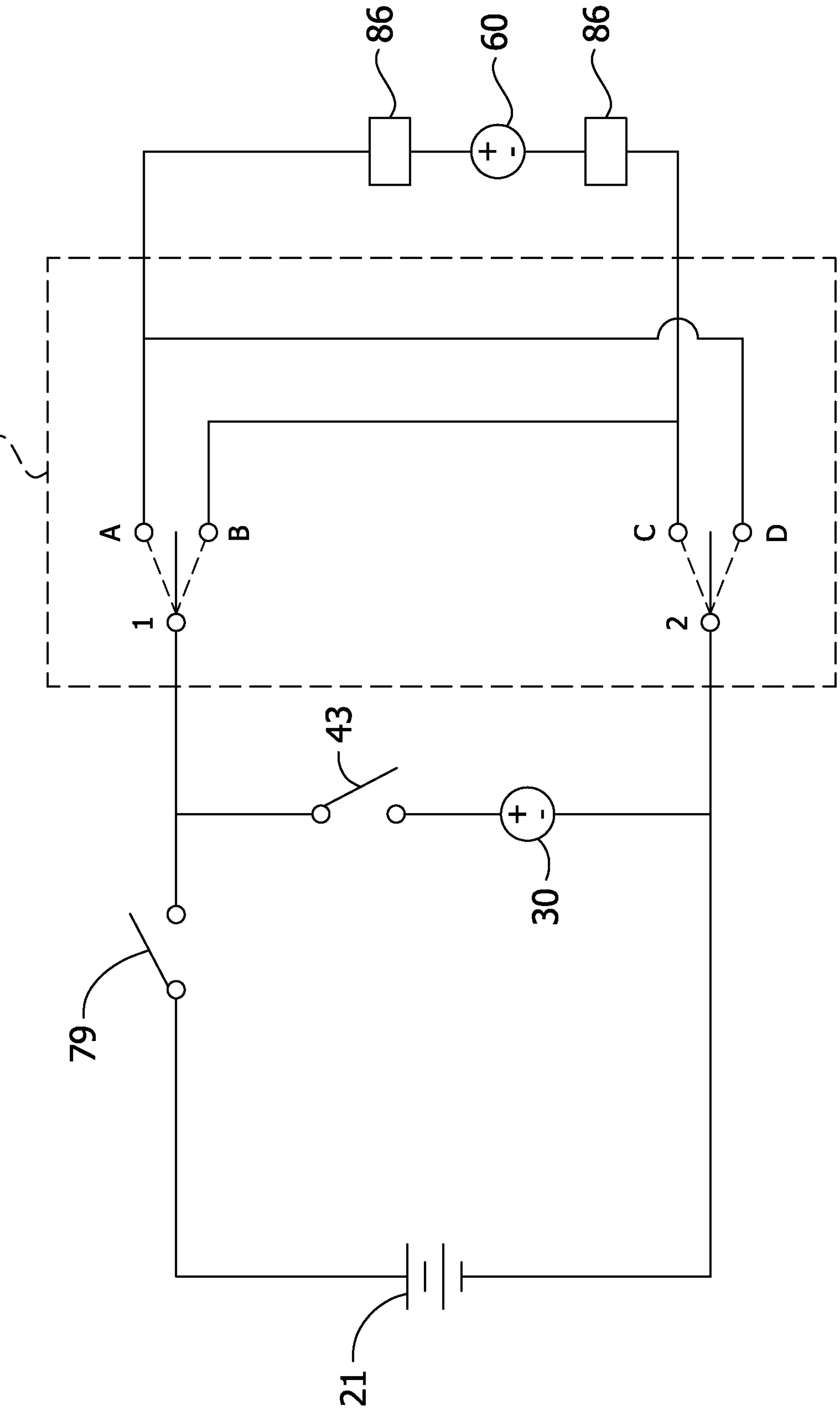
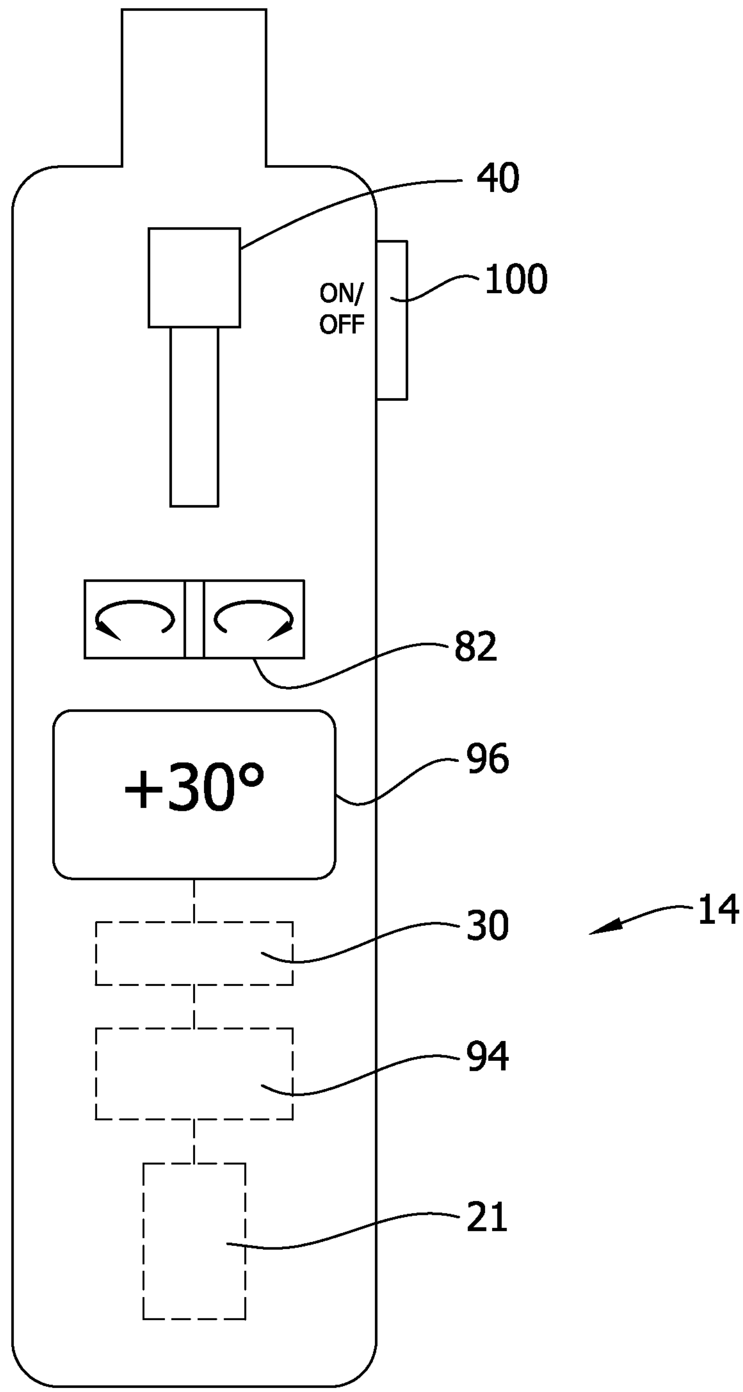
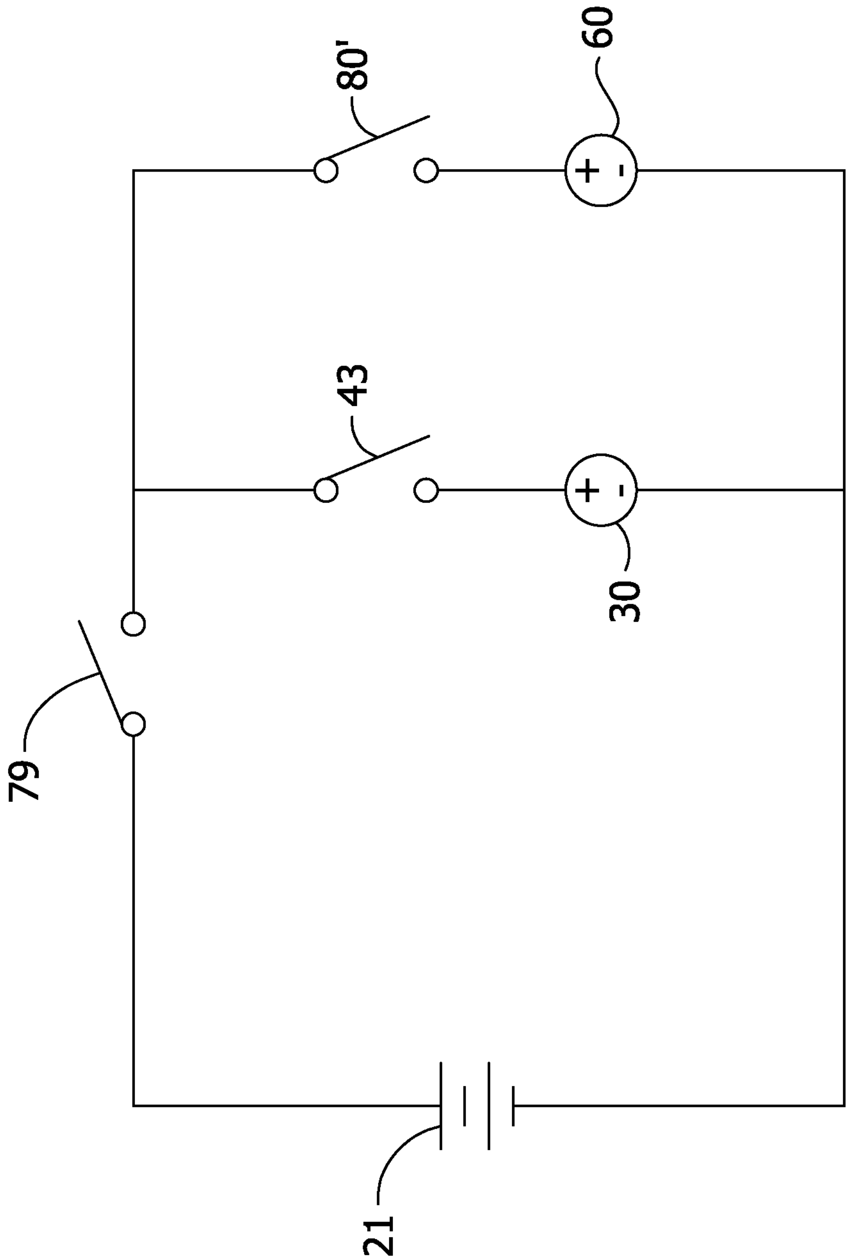


FIG. 9

FIG. 10





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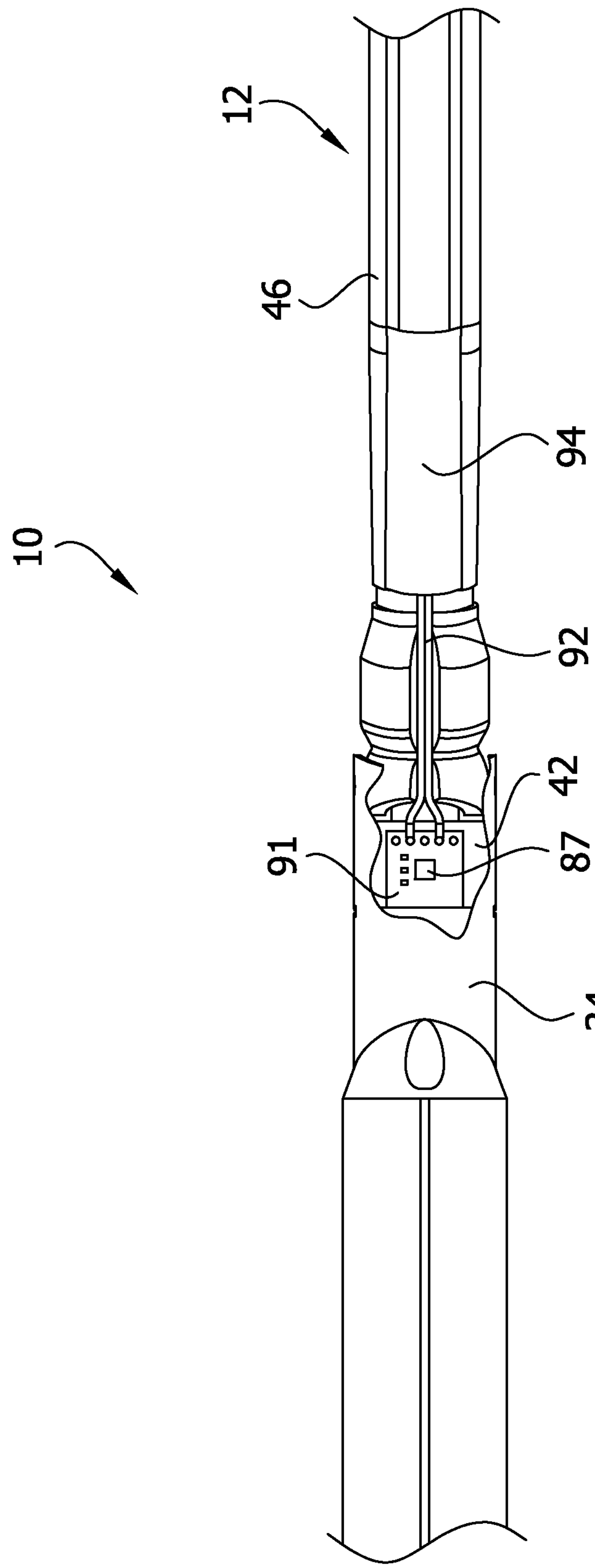

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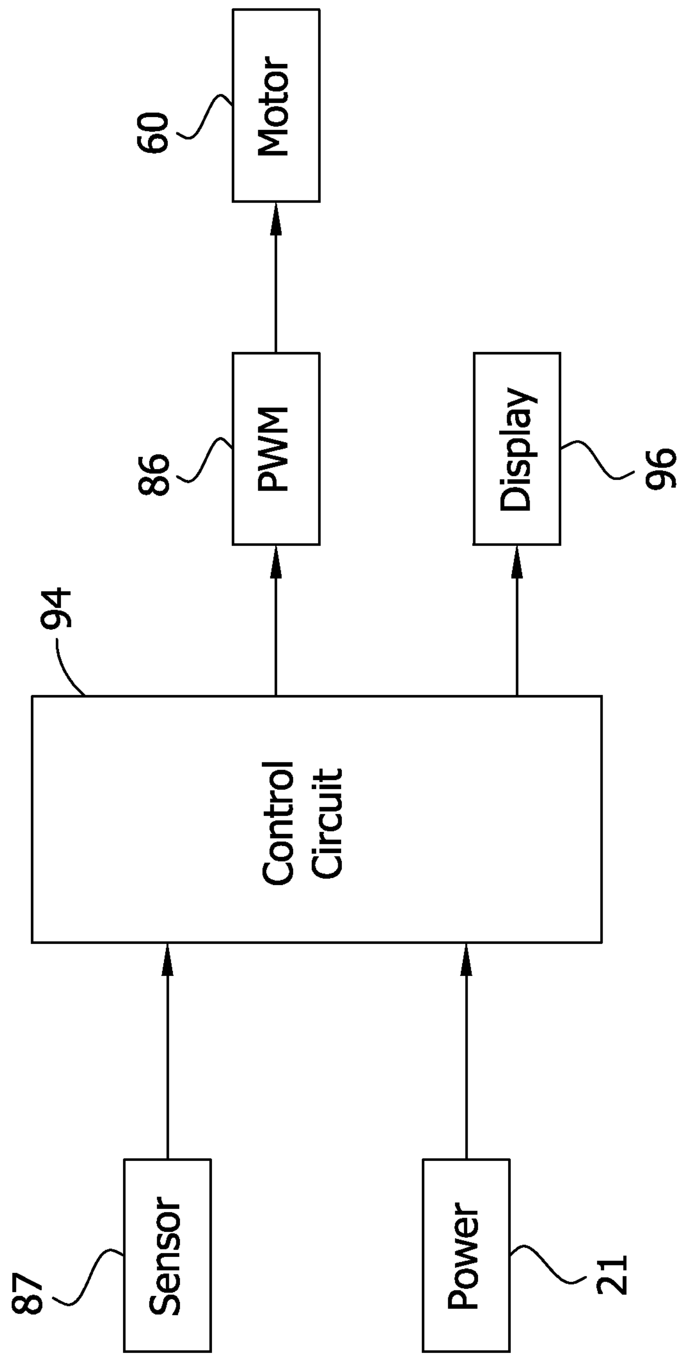
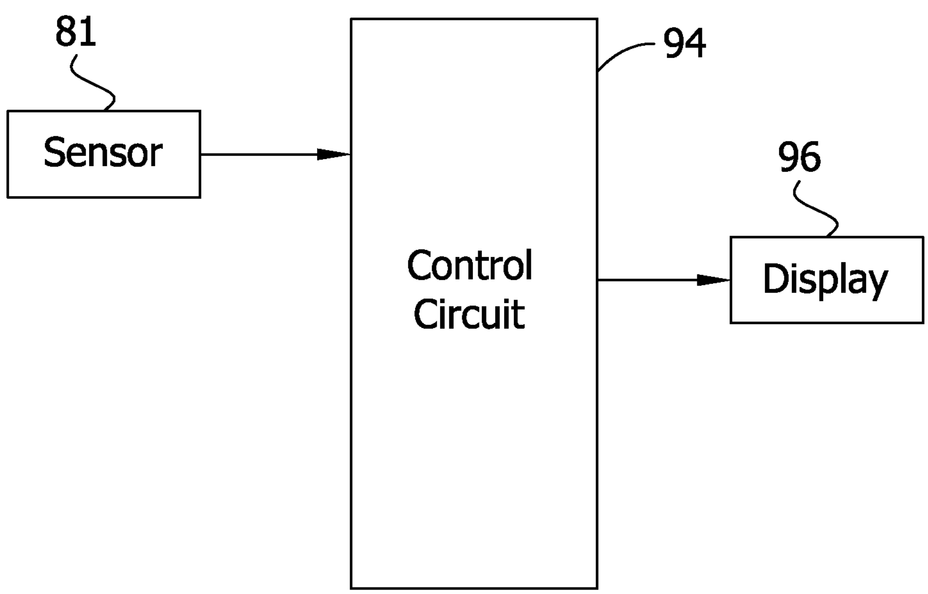


Motor
60
PWM
86
Display
96
94
Control
Circuit
Sensor
87
Power
21

FIG. 13

FIG. 14



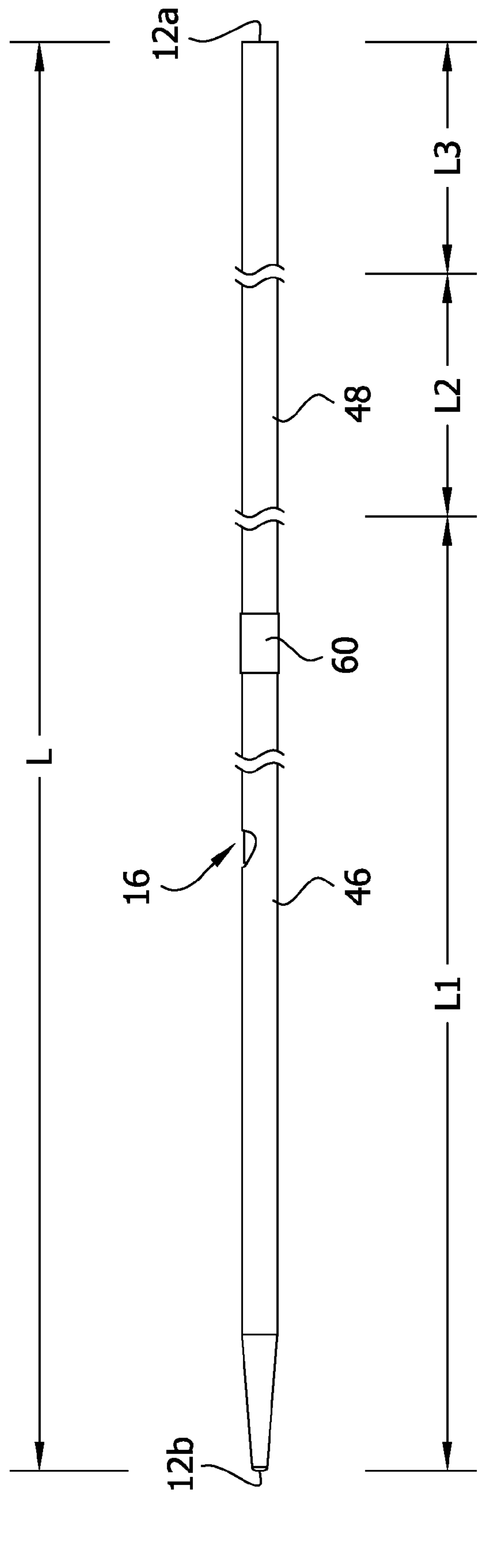


FIG. 15

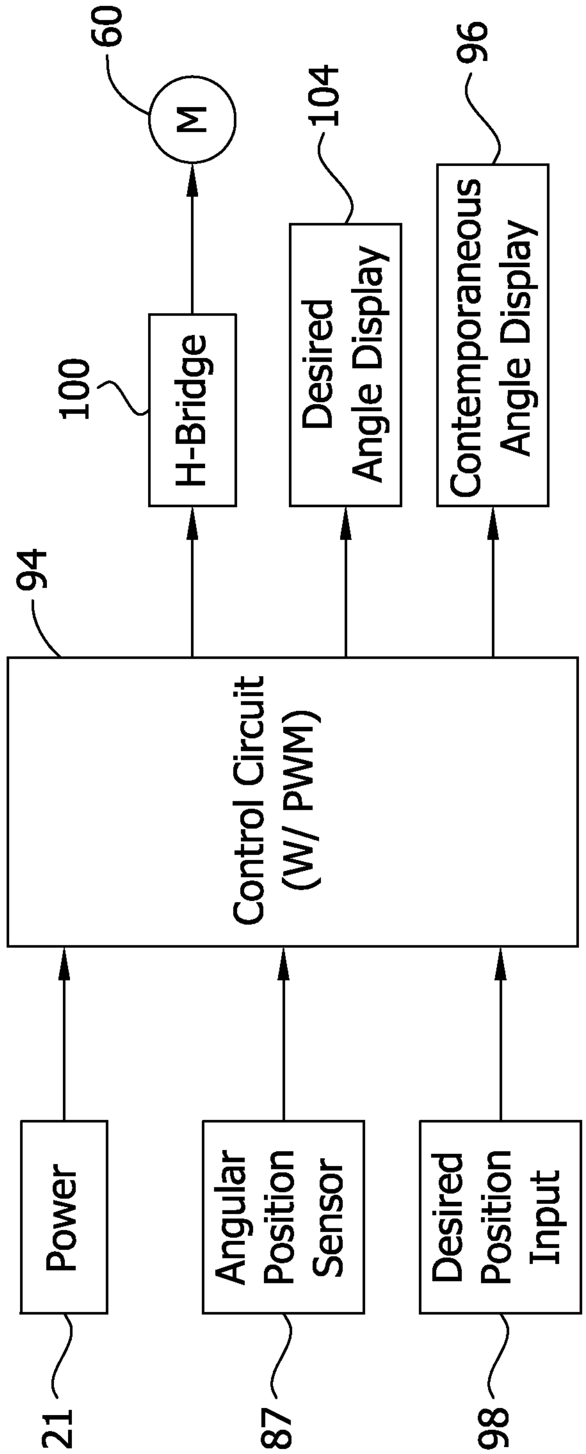
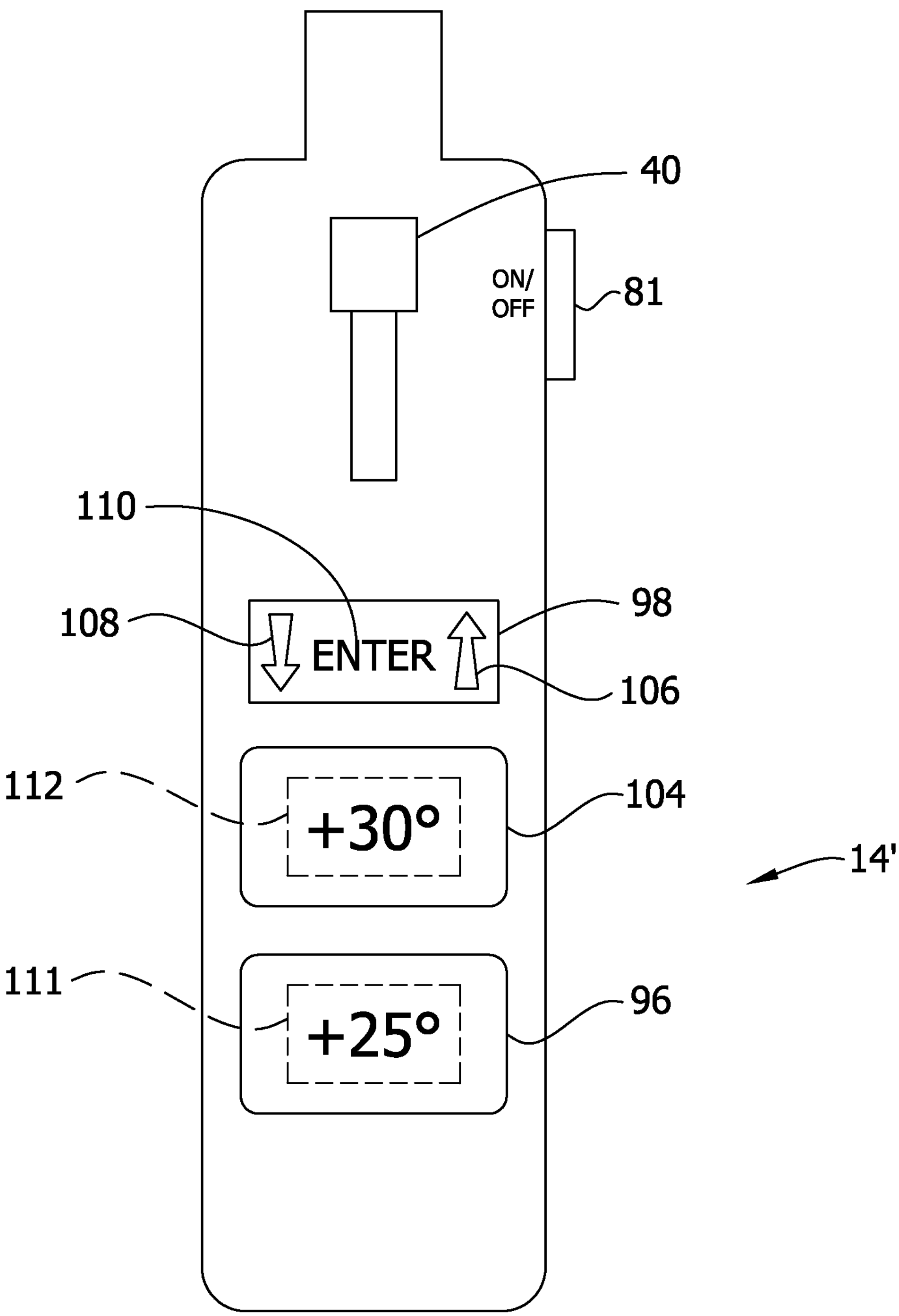

Power
Angular Position Sensor
Desired Position Input
Control Circuit (W/ PWM)
H-Bridge
M
Desired Angle Display
Contemporaneous Angle Display
21
87
98
94
100
60
104
96

FIG. 16

FIG. 17



TISSUE-REMOVING CATHETER INCLUDING ANGULAR DISPLACEMENT SENSOR

FIELD OF THE DISCLOSURE

The present disclosure generally relates to a tissue-removing catheter including an angular displacement sensor.

BACKGROUND OF THE DISCLOSURE

Debulking or tissue-removing catheters are used to remove unwanted tissue from the body. As an example, atherectomy catheters are used to remove material from a blood vessel to open the blood vessel and improve blood flow through the vessel.

SUMMARY OF THE DISCLOSURE

In one aspect, a tissue-removing catheter for removing tissue from a body lumen includes a tissue-removing element. The tissue-removing element may be coupled to a first longitudinal portion of the catheter body. An angular-displacement sensor may be coupled to the catheter body for detecting an angular displacement of at least the first longitudinal portion of the catheter body relative to the rotational axis when the first longitudinal body portion is rotated about the rotational axis.

In another aspect, the tissue-removing element may be rotatable about a rotational axis to adjust an angular tissue-removing position of the tissue-removing element relative to the body lumen when the catheter body is inserted in the body lumen. The angular-displacement sensor may be generally adjacent the tissue-removing element for detecting an angular displacement of the tissue-removing element relative to the body lumen when the tissue-removing element is rotated about the rotational axis.

Other features will be in part apparent and in part pointed out hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective of a catheter body and a schematic representation of a handle, each of which are part of a catheter;

FIG. **2** is an enlarged fragmentary cross section of the catheter body, illustrating a tissue-removing element in a deployed position;

FIG. **3** is an enlarged fragmentary side elevation of the catheter body;

FIG. **4** is an enlarged fragmentary side elevation of the catheter body received in a blood vessel shown in section;

FIG. **5** is a schematic cross section of the catheter body received in a blood vessel taken in the plane defined by the line **5-5** in FIG. **4**;

FIG. **6** is an enlarged fragmentary section taken in the plane defined by the line **6-6** in FIG. **8**;

FIG. **7** is similar to FIG. **5**, except illustrating a change in an angular tissue-removing position of the tissue-removing element of the catheter body;

FIG. **8** is an enlarged fragmentary bottom elevation of the catheter body;

FIG. **9** is an electrical diagram of electrical components of the catheter according to one or more embodiments;

FIG. **10** is an enlarged schematic of the handle in FIG. **1**;

FIG. **11** is an electrical diagram of electrical components of the catheter according to one or more embodiments;

FIG. **12** is an enlarged fragmentary bottom elevation of the catheter body, including portions broken away to show underlying components;

FIG. **13** is a block diagram illustrating a control circuit and components in communication with the control circuit according to the embodiment illustrated in FIG. **9**;

FIG. **14** is a block diagram illustrating a control circuit and components in communication with the control circuit according to the embodiment illustrated in FIG. **11**;

FIG. **15** is a schematic of the catheter body shown in a linear configuration;

FIG. **16** is a block diagram illustrating a control circuit and components in communication with the control circuit according to one or more embodiments; and

FIG. **17** is an enlarged schematic of one embodiment of a handle for use with the embodiment illustrated in FIG. **16**.

Corresponding reference characters indicate corresponding parts throughout the drawings.

DETAILED DESCRIPTION OF THE DISCLOSURE

Embodiments of a tissue-removing catheter having improved angular tissue-removing positioning within a body lumen for removing tissue from the body lumen are disclosed. In particular, the illustrated catheter embodiments are particularly suitable for removing (i.e., excising) plaque tissue from a blood vessel (e.g., peripheral arterial or peripheral venous wall). Features of the disclosed embodiments, however, may also be suitable for treating chronic total occlusion (CTO) of blood vessels, particularly peripheral arteries, and stenoses of other body lumens and other hyperplastic and neoplastic conditions in other body lumens, such as the ureter, the biliary duct, respiratory passages, the pancreatic duct, the lymphatic duct, and the like. Neoplastic cell growth will often occur as a result of a tumor surrounding and intruding into a body lumen. Removal of such material can thus be beneficial to maintain patency of the body lumen. While the remaining discussion is directed toward catheters for removing tissue from, and penetrating occlusions in, blood vessels (e.g., atheromatous or thrombotic occlusive material in an artery, or other occlusions in veins), it will be appreciated that the teachings of the present disclosure apply equally to other types of tissue-removing catheters, including, but not limited to, catheters for penetrating and/or removing tissue from a variety of occlusive, stenotic, or hyperplastic material in a variety of body lumens.

Referring to FIG. **1**, a tissue-removing catheter, in accordance with one or more embodiments of the present disclosure, is generally indicated at reference numeral **10**. The catheter **10** comprises an elongate catheter body, generally indicated at **12**, having opposite proximal and distal ends **12***a*, **12***b*, respectively, and a longitudinal axis A1 (FIG. **3**) extending between the proximal and distal ends. A handle or control unit, generally indicated at **14**, is attachable to the proximal end **21***a* of the catheter body **12**, although the handle may be fixedly attached to the catheter body in other embodiments. A tissue-removing element, generally indicated at **16**, generally adjacent the distal end **12***b* of the catheter body **12**, is configured to remove (e.g., cut) tissue from the body lumen and direct the removed tissue into a tissue container **17**.

Referring to FIG. **2**, in the illustrated embodiment, the tissue-removing element **16** comprises a rotatable cutting element that is rotatable about a rotation axis RA1 for cutting tissue. The illustrated cutting element **16** has a cutting edge **18** facing distally, although in other embodiments the cutting edge may face proximally, and a cup-shaped surface **20** for directing removed tissue distally into the tissue container **17** of the catheter body **12**. In other embodiments, the tissue-removing element may have other configurations for cutting tissue, or may be configured to remove tissue in other ways. For example, the tissue-removing element may be configured to ablate tissue, or abrade tissue, or otherwise remove tissue from the body lumen. Moreover, the tissue-removing element may not be rotatable relative to the catheter body.

Referring still to FIG. **2**, a tissue-removing driveshaft **26** is operatively connected to a stem **28** of the tissue-removing element **16** (e.g., fixedly secured thereto) for imparting rotation to the tissue-removing element. The tissue-removing driveshaft **26** (e.g., a coiled driveshaft) extends through the catheter body **12** and is operatively connectable to an electric driveshaft motor **30** (FIG. **10**), or other prime mover, in the handle **14** for driving rotation of the driveshaft, and in turn, driving rotation of the tissue-removing element **16**, relative to the catheter body. The driveshaft motor **30** is electrically connected to a power source **21** (FIG. **10**) in the handle **14**. In the illustrated embodiment, the driveshaft **26** is movable longitudinally within the catheter body **12** to impart longitudinal movement of the tissue-removing element **16** relative to the catheter body. Longitudinal movement of the tissue-removing element **16** actuates deployment and storage of the tissue-removing element relative to a tissue-removing housing **34**, which is part of the catheter body **12**. The tissue-removing housing **34** (e.g., a proximal end portion thereof) pivots about a pivot axis PA (FIG. **3**) that is generally transverse to the longitudinal axis A**1** of the catheter body. A distal portion of the housing **34** forms the tissue container **17**, although the housing and the tissue collection chamber may be formed separately.

The tissue-removing element **16** is movable between a stored position (not shown) and a deployed position (FIGS. **1** and **2**). In the stored position, the tissue-removing element **16** is received in the housing **34** and is not exposed through a window or side opening **38** of the housing. To deploy the tissue-removing element **16**, the driveshaft **26** is moved proximally relative to the catheter body **12**, such as by moving a lever or other actuator **40** (FIG. **1**) on the handle **14** that is operatively connected to the driveshaft, to impart proximal movement of the tissue-removing element **16** relative to the housing **34**. Referring to FIG. **2**, as the tissue-removing element **16** moves proximally, the tissue-removing element, which acts as a cam, engages and moves longitudinally along an internal cam follower **42** of the housing **34**, causing the housing to pivot about the pivot axis PA (FIG. **4**) and the tissue-removing element to extend partially out of the window **38**. A switch **43** (FIG. **11**) may be coupled to the actuator **40** such that the driveshaft motor **30** activates (i.e., turns on) to impart rotation to the driveshaft **26** when the tissue-removing element **16** is deployed. To return the tissue-removing element **16** to its stored, non-deployed position, the driveshaft **26** is moved distally, such as by moving the actuator **40** distally, to impart distal movement of the tissue-removing element **16** along the cam follower **42**. Distal movement of the tissue-removing element **16** causes the housing **34** to pivot or deflect back about the pivot axis PA so that the tissue-removing element is received in the housing **34** and does not extend outside the window **38**. When the tissue-removing element **16** is in its stored position, the driveshaft motor **30** is deactivated (i.e., turned off). It is understood that a catheter **10** constructed according to the principles of the present disclosure may not include a deployment mechanism (e.g., the tissue-removing element or other functional element may always be deployed or may remain within the catheter body).

Referring to FIG. **3**, the catheter body **12** includes a first (distal) longitudinal body portion **46** defining a distal portion of the catheter body, and a second (proximal) longitudinal body portion **48** that is proximal of the first (distal) longitudinal body portion. In the illustrated embodiment, the second (proximal) longitudinal body portion **48** extends from adjacent a proximal end of the first (distal) longitudinal body portion **46** toward the proximal end **12***a* of the catheter body **12**. As explained in more detail below, the first (distal) longitudinal body portion **46** is selectively rotatable along its length and relative to the second (proximal) longitudinal body portion **48** about a second rotational axis A2 (FIG. **5**). In particular, the first (distal) longitudinal body portion **46** is operatively connected to an angular-positioning mechanism **60** for imparting rotation of the first (distal) longitudinal body portion along its length and relative to the second (proximal) longitudinal body portion **48**. The first and second (proximal) longitudinal body portions **46**, **48**, respectively, are suitably flexible for navigating the catheter body **12** through tortuous paths within the body lumen BL. The first (distal) longitudinal body portion **46** may comprise a torque tube (e.g., a coiled member) for transmitting torque from its proximal end toward its distal end, as explained in more detail below. In particular, the torque tube of the first longitudinal portion **46** may be formed from coiled stainless steel or other materials and constructions. The second (proximal) longitudinal body portion **48** may also comprise a torque tube, although for reasons explained in more detail below, the second (proximal) longitudinal body portion may not include a torque tube as it may not be necessary for the second (proximal) longitudinal body portion to be capable of effectively transmitting torque from its proximal end toward its distal end.

Referring still to FIG. **3**, the catheter **10** comprises an apposition member, generally indicated at **52**, that is configured to apply an apposition force in a generally radial direction relative to a longitudinal axis A**1** of the catheter body **12** to direct the tissue-removing element **16** toward a peripheral (or circumferential) portion of the body lumen when the catheter is inserted in the body lumen BL defined by the blood vessel V. In the illustrated embodiment, the apposition member **52** comprises a jogged portion of the first (distal) longitudinal body portion **46** that is biased or preformed in a jogged or curved configuration. In other embodiments, the apposition member **52** may be of other constructions for directing the tissue-removing element **16** toward a peripheral portion of the body lumen BL. For example, in other embodiments the apposition member may comprise an inflatable member secured adjacent the tissue-removing element **16** on a side of the housing **34** that is opposite the window **38**. In other embodiments, the housing **34** may function as the apposition member, whereby pivoting of the housing directs the tissue-removing element **16** toward a peripheral or circumferential portion of the body lumen. The apposition member may be of other constructions.

As can be seen in FIG. **4**, when the catheter **10** is inserted in the body lumen BL, the apposition member **52** engages a peripheral portion of the body lumen BL defined by the blood vessel V to maintain the tissue-removing element **16** and/or the window **38** (FIG. **2**) in apposition with an opposite peripheral portion of the body lumen that is generally diametrically opposite (e.g., 180 degrees from) the peripheral portion engaged by the apposition member. This angular position of the tissue-removing element **16** relative to the longitudinal axis A2 of the body lumen BL is referred to herein as the "angular tissue-removing position." In the schematic of FIG. **5**, the angular position of the tissue-removing element **16** is offset 0 degrees from a reference plane RP passing through the body lumen BL. In general, the angular tissue-removing position of a tissue-removing element **16** is about 180 degrees offset from the location of the force applied to the body lumen BL by the apposition member.

Referring to FIG. **6**, the angular-positioning mechanism **60** allows the user to rotate the apposition member **52** (and this the tissue-removing element **16**) within the body lumen BL to adjust the angular tissue-removing position of the tissue-removing element relative to the longitudinal axis A2 of the body lumen, without manually rotating or torquing the second (proximal) longitudinal body portion **48** of the catheter body. In particular, the angular-positioning mechanism **60** is operatively connected to the apposition member **52** and configured to rotate the apposition member relative to the second (proximal) longitudinal body portion **48** of the catheter body **12** about the rotational axis A2 to adjust the angular tissue-removing position of the tissue-removing element relative to the longitudinal axis A2 of the body lumen BL when the catheter **10** is inserted in the body lumen. In the illustrated embodiment, the angular-positioning mechanism **60** includes a prime mover, such as an electric motor, located between the first (distal) and second (proximal) longitudinal body portions **46**, **48** and electrically connectable to a power source, such as the same power source **21** electrically connectable to the driveshaft motor **30**, or a different power source. In particular, the illustrated angular-positioning motor **60** is a pass through electric motor including a rotor **63**, a stator **64**, and a hollow output shaft **65** connected to the first (distal) longitudinal body portion **46**. The angular-positioning motor **60** has an opening **68** that is coaxial with lumens **70**, **72** defined by the respective first (distal) and second (proximal) longitudinal body portions **46**, **48**. The driveshaft **26** passes through the opening **68** in the angular-positioning motor **60** and through the lumens **70**, **72**. The angular-positioning motor **60** may be other types of electric motors, or other types of prime movers. In other embodiments, the angular-positioning mechanism **60** may be located elsewhere on the catheter **10**, such as another location on the catheter body **12** or in the handle **14**, for rotating at least the first (distal) longitudinal body portion **46** about its length.

Referring to FIG. **7**, the illustrated apposition member **52** functions as an eccentric because it is not coaxial with (i.e., is off-center from) the rotational axis A2 of the angular-positioning mechanism **60**. In effect, rotating the apposition member **52** about the rotational axis A2 adjusts the angular tissue-removing position relative to the body lumen BL and allows the user to direct the tissue-removing element **16** toward a different peripheral portion of the body lumen. For example, in the schematic illustration of FIG. **7**, the apposition member **52** is rotated relative to the axis A2 of the body lumen BL so that the angular tissue-removing position of the tissue-removing element **16** (shown in solid lines) is offset an angle α, measuring about 60 degrees in the clockwise direction, from a reference tissue-removing position (shown in broken lines) of the tissue-removing element.

Referring to FIG. **8**, the angular-positioning motor **60** is electrically connectable to the power source **21** via one or more electrical conductors **74**, such as wires or flex circuits, running along the catheter body **12**. In the illustrated embodiment, the electrical conductors **74** are received in a wire lumen **78** that is separate and free from communication with the driveshaft lumens **70**, **72** of the catheter body **12**. In other embodiments, the electrical conductors may be received in the driveshaft lumens **70**, **72**. The angular-positioning motor **60** may be powered in other ways, including a local battery or in other ways, whereby the electrical conductors may be omitted.

An electrical schematic including the power source **21**, the driveshaft motor **30**, and the angular-positioning motor **60** is shown in FIG. **9**. The catheter **10** includes a power switch **79** for selectively connecting the power source **21** to respective switches **43**, **80** for the driveshaft motor **30** and the angular-positioning motor **60**. In this illustrated embodiment, an actuator **81** (e.g., toggle, as illustrated, or a lever or slide or button), as shown in FIG. **10**, is provided on the handle **14** to selectively actuate the switch **79**. The switch **80** for selectively connecting the angular-positioning motor **60** to the electrical power source **21** to operate the angular-positioning motor may be a mechanical switch (as illustrated) or a solid-state switch or other types of switches. In this illustrated embodiment, an actuator **82** (e.g., toggle, as illustrated, or a lever or slide or button), as shown in FIG. **10**, is provided on the handle **14** to selectively actuate the switch **80**. In the embodiment illustrated in FIG. **9**, the switch **80** allows the user to selectively control the direction of rotation of the angular-positioning motor **60** and the apposition member **52**. As an example, the switch **80** may be a double pole center off switch. When the actuator **82** is in the "off" position (i.e., neither rotational direction is selected), the terminal sets **1**A, **1**B, **2**C, and **2**D are open and the angular-positioning motor **60** is not activated. To move the apposition member **52** in the clockwise direction (and thus adjust the angular tissue-removing position of the tissue-removing element **16** in the body lumen BL), the user selects the "clockwise" direction on the actuator **82**. For example, the user may depress the right side of the illustrated toggle actuator **82**, whereby the terminals sets **1**A and **2**C are closed and the terminal sets **1**B and **2**D are open. Electrical current flows through the closed terminal sets **1**A and **2**D powers rotation of the angular-positioning motor **60** in the clockwise direction to rotate the apposition member **52** in the clockwise direction. To move the apposition member **52** in the counterclockwise direction (and thus adjust the angular tissue-removing position of the tissue-removing element **16** in the body lumen BL), the user selects the "counterclockwise" direction on the actuator **82**. For example, the user may depress the left side of the illustrated toggle actuator **82** to actuate closing of the terminals sets **1**B and **2**D, while the terminal sets **1**A and **2**C are open. Electrical current flows through the closed terminal sets **1**B and **2**D powers the angular-positioning motor **60** in the counterclockwise direction to rotate the apposition member in the counterclockwise direction.

Referring still to FIG. **9**, one or more pulse width modulators (PWM) **86** are electrically connected to the angular-positioning motor **60** for regulating a duty cycle supplied to the angular-positioning motor from the power source **21**. In this example, the electrical current is received from the same power source **21** as the driveshaft motor **30**. The modulators **86** effectively regulate the duty cycle supplied to the angular-positioning motor **60** to regulate the rotational speed of the motor in either direction. It is envisioned that the one or more modulators **86** will regulate the speed of the angular-positioning motor **60** to substantially less than that of the driveshaft **26** (e.g., from about 1 rpm to about 60 rpm). The one or more modulators **86** may be received in the handle **14** or in the catheter body **12**. It is understood that catheter may not include such a pulse with modulator **86** in other embodiments.

The switch **80** may be of other types of switches. For example, in the embodiment illustrated in FIG. **11**, the switch **80'** is a single pole, single throw switch, whereby when the switch is on (i.e., the circuit path is closed) power is supplied to the angular-positioning motor **60** (the angular-positioning motor is on and operating), and when the switch is off (i.e., the circuit path is open) power is interrupted to the angular-positioning motor (the angular-positioning motor is off and non-operating). In this embodiment, the angular-positioning motor **60** is configured to rotate in only one-direction (e.g., clockwise).

As shown in FIG. **12** (and also shown in FIG. **2**), the illustrated catheter **10** includes an angular-displacement sensor **87** in addition to the angular-positioning mechanism **60**. In other embodiments the catheter **10** may include one of the angular-positioning mechanism **60** and the angular-displacement sensor **87**, and not the other. The angular-displacement sensor **87** is used for determining the angular tissue-removing position of the tissue-removing element **16** relative to longitudinal axis A**2** of the body lumen BL. In the illustrated embodiment, the angular-positioning mechanism **60** and the angular-displacement sensor **87** together allow the user to determine the angular tissue-removing position of the tissue-removing element in the body lumen BL during treatment and adjust this angular position a selected magnitude and/or direction, without manually rotating or torquing the second (proximal) longitudinal end body portion **48** of the catheter body **12**.

Referring still to FIG. **12** (also shown in FIG. **2**), the angular-displacement sensor **87** is associated with the first (distal) longitudinal end body portion **46** of the catheter body **12** and is configured to detect the angular displacement of the apposition member **52** (and the angular tissue-removing position of the tissue-removing element **16** relative to the longitudinal axis A**2** of the body lumen BL). In the illustrated embodiment, the angular-displacement sensor **16** is fixedly secured to the housing **34**, and more particularly, to the cam follower or ramp **42** within the housing. A bottom side of the ramp **42** has a cutout or recess **88** (see FIG. **2**) in which the angular-displacement sensor **87** is received. In the illustrated embodiment, the angular-displacement sensor **87** is a solid-state sensor, such as an integrated circuit mounted on a circuit board **90**. For example, in one embodiment the angular-displacement sensor **87** may be a gyroscope. The angular-displacement sensor **87** may be other types of sensors, other than a gyroscope. For example, the angular-displacement sensor **87** may be a magnetometric sensor, which is used to determine the angular tissue-removing position of the tissue-removing element **16** relative to the magnetic fields of the earth. The angular-displacement sensor **87** may be secured to the catheter body **12** at other locations for detecting the angular displacement of the apposition member **52** and the displacement of the angular tissue-removing position of the tissue-removing element **16**. The catheter **10** includes one or more electrical conductors **92** (e.g., wires) electrically connected to the angular-displacement sensor **87** and running along the catheter body **12** toward the proximal end **12***a* of the body. In particular, the electrical conductors **92** are received in a wire lumen **94** at the first (distal) longitudinal body portion **46** and in the wire lumen **78** at the second (proximal) longitudinal body portion **48**. The lumens **78**, **94** are separate and free from communication with the driveshaft lumens **70**, **72**. The electrical conductors **92** are electrically connectable to a control circuit **94** and the power source **21**. The control circuit **94** may be provided in the handle **14**, as illustrated, or the control circuit may be provided in the catheter body **12**, such as on the same circuit board **91** as the angular-displacement sensor **87**.

Referring to FIG. **13**, in the illustrated embodiment, the control circuit **94** is configured (e.g., programmed) to receive electrical signals from the angular-displacement sensor **87**, compute the angular displacement of the tissue-removing element **16**, and communicate the magnitude and direction of the displacement to the user via a user interface **96**. In the illustrated embodiment, the user interface **96** comprises a display (e.g., an LCD screen or other electronic display screen) on the handle **14** (See FIGS. **1** and **10**). As explained in more detail below when discussing an exemplary method of use, the control circuit **94** is configured (e.g., programmed) to compute the angular displacement of the tissue-removing element **16** (and/or the angular displacement of the apposition member **52**) relative to a reference angular tissue-removing position based on the electrical signals received from the angular-displacement sensor **87**. The control circuit **94** then displays the computed angular displacement on the display **96** for the user, such as illustrated in FIG. **10**. Thus, as the user actuates operation of the angular-positioning motor **60**, the user can observe the displayed angular displacement on the display **96** as feedback to make a determination as to the contemporaneous angular tissue-removing position of the tissue-removing element **16** in the body lumen BL. As also shown in FIG. **13**, the power source **21** and the pulse width modulator(s) **86** may be in electrical communication with the control circuit **94**. The control circuit monitors the amount of electrical power being drawn by angular-positioning motor **60** and/or the driveshaft motor **30**. Based on the amount of electrical power being supplied to one or both of the motors **60**, **30**, the control circuit **94** can adjust the duty cycle supplied to the angular-positioning motor **60**, through communication with the pulse width modulator(s) **86**, to ensure that the motor rotates at a desired speed.

FIG. **14** illustrates an electrical diagram for the embodiment illustrated in FIG. **11**. As shown in FIG. **14**, the control circuit **94** is in electrical communication with the sensor **87** and the display **96** in the manner set forth above with respect to FIG. **13**. However, in this example the catheter **10** does not include a pulse width modulator, so the control circuit is not in communication with the power source **21** or the angular-positioning motor **60** for regulating power supplied to the motor.

In an exemplary method of using the illustrated catheter **10**, the distal end **12***b* of the catheter body **12** may be inserted into the body lumen BL defined by the blood vessel V, such as a peripheral artery of a patient's leg, and traversed through the body lumen to a target site. For example, the target site may be a stenotic lesion T (i.e., build-up of plaque) in the vessel V. Upon reaching the target site T in the vessel V and prior to deploying the tissue-removing element **16**, the control circuit **94** may compute the contemporaneous angular tissue-removing position of the tissue-removing element **16** and store the computed angular position in the memory as a reference angular tissue-removing position. In the illustrated example, the power actuator **81** may activate the angular position sensor **87**, and the control circuit **94** is programmed to store the first computed contemporaneous angular tissue-removing position of the tissue-removing element **16** as the reference angular tissue-removing position. In another example, the user interface (e.g., display) **96** may be configured to allow the user to instruct the control circuit **94** when to store a computed contemporaneous angular tissue-removing position of the tissue-removing element **16** as the initial or reference angular tissue-removing position. For example, the display **96** may be a touch-screen that includes a graphical image (not shown) for allowing the user to select when to store a computed contemporaneous angular tissue-removing position of the tissue-removing element **16** as the reference angular tissue-removing position. In yet another example, upon the first deployment of the tissue-removing element **16** and activation of the driveshaft motor **30** (such as by sliding the actuator **40** proximally), the control circuit **94** may compute and store the contemporaneous angular tissue-removing position of the tissue-removing element **16** as the initial angular tissue-removing position. Other ways of setting and storing the initial angular tissue-removing position of the tissue-removing element **16** do not depart from the scope of the present invention.

After computing the reference angular position of the tissue-removing element **16**, the control circuit **94** may be programmed to communicate to the user that the tissue-removing element **16** is positioned at 0 degrees. For example, the display **96** (e.g., an LCD display or other display) may read "0°." With the tissue-removing element **16** in the initial or reference angular tissue-removing position, the user may deploy the tissue-removing element **16** (such as in the manner set forth above) and with driveshaft motor **30** rotating the tissue-removing element, the user may make an initial "tissue-removing pass" through the stenotic lesion T by moving the catheter body **12** distally through the body lumen BL, such that the tissue-removing element cuts the stenotic lesion at the initial angular location within the body lumen BL.

During the tissue-removing pass, there may be a tendency for the catheter body **12** to rotate or become angularly displaced during a tissue-removing pass because the distal end **12***b* tends to travel along a path of least resistance in the body lumen BL. This tendency of the distal end **12***b* of the catheter body **12** to travel along a path of least resistance may be referred to as "guttering," when the tissue-removing element **16** deviates from its angular tissue-removing position. In one example, the control circuit **94** may be configured (e.g., programmed) to continue to receive signals from the angular-displacement sensor **87** and compute and display the angular displacement of the tissue-removing element within the body lumen BL. Accordingly, as the user is moving the catheter body **12** distally, the user can observe the angular tissue-removing position, which corresponds to the angular position of the "tissue-removing pass" within the body lumen BL. In one example, the control circuit **94** may be programmed (i.e., configured) to inhibit power from being supplied to the angular-positioning motor **60** when the tissue-removing element **16** is deployed, thereby inhibiting the user from adjusting the angular tissue-removing position of the tissue-removing element during a tissue-removing pass. Thus, if the user is notified that the tissue-removing element **16** has deviated from the desired angular location, the user can store the tissue-removing element **16**, move the catheter body **12** proximally, and then attempt to make another tissue-removing pass in an attempt to avoid guttering. Alternatively, where the control circuit **94** is not programmed to inhibit power from being supplied to the angular-positioning motor **60** when the tissue-removing element **16** is deployed, the user may make adjustments to the angular tissue-removing position, such as by using the actuator **82**, to maintain the tissue-removing element **16** at the desired angular tissue-removing position during a tissue-removing pass. In another example, the control circuit **94** may be configured (e.g., programmed) to indicate to the user that the tissue-removing element **16** has deviated from the desired angular location within the body lumen (i.e., deviated a selected threshold magnitude, such as 20 degrees or 15 degrees or 10 degrees or 5 degrees). For example, the control circuit **94** may be configured (i.e., programmed) to flash the read-out on the display **96** or activate another audio or visual indicator, such as an LED on the handle.

After making the initial tissue-removing pass, the tissue-removing element **16** may be moved to its non-deployed position (such as in a manner described above), and the catheter body **12** may be moved proximally, toward the proximal end of the target site within the body lumen BL. The user may check the lesion T under fluorescence or other imaging means to make a determination of the desired angular location of the next tissue-removing pass through the lesion. The user may then adjust the angular tissue-removing position of the tissue-removing element **16** by using the actuator **82**, and then deploy the tissue-removing element and move the catheter body **12** distally to make the desired second tissue-removing pass. After making the second tissue-removing pass, the above steps of i) storing the tissue-removing element **16**, ii) moving the catheter proximally to a proximal location of the body lesion T, iii) checking the lesion under fluorescence to make a determination of the next desired tissue-removing pass through the lesion, iv) adjusting the angular tissue-removing position of the tissue-removing element to a desired position, and v) making an additional "tissue-removing pass" through the lesion, are repeated a desired number of times. The desired angular tissue-removing position of the tissue-removing element **16** may be made relative to the initial reference angular position of the first tissue-removing pass. Alternatively, the control circuit **94** may be configured to allow the user to selectively change the stored reference angular position used for subsequent tissue-removing passes. For example, after making the second tissue-removing pass, the user may choose to change the reference angular tissue-removing position for the third tissue-removing pass to be the angular location of the second tissue-removing pass, as opposed to the angular location of the first tissue-removing pass.

As an example, as shown schematically in FIG. **7**, the user may desire to make a second tissue-removing pass at a peripheral portion of the body lumen BL that is offset about 30 degrees clockwise from the initial tissue-removing pass. Accordingly, the user may depress the right side of the toggle actuator **82** to activate the prime mover **60** and clockwise rotation of the apposition member **52**, thus adjusting the angular tissue-removing position of the tissue-removing element **16**. As the user holds down the right side of the toggle actuator **82** (alternatively, the right side of the toggle may remain depressed) and the apposition member **52** and first (distal) longitudinal body portion **46** rotates clockwise, the user observes the readout on the display **96**, which indicates the magnitude and direction of the angular displacement of the tissue-removing position of the tissue-removing element **16**. For example, a "+" indicates that the angular displacement of the angular tissue-removing position of the tissue-removing element **16** is in the clockwise direction, and a "−" indicates that the angular tissue-removing displacement is in the counterclockwise direction. When the display **96** reads "+30°" or some other readout corresponding to the desired angular displacement, the user disengages the right side of the toggle actuator **82** (alternatively, the user moves the toggle actuator to its center "off" position), so that the angular-positioning motor **60** deactivates and ceases rotation of the apposition member **52**. Next, the tissue-removing element **16** is deployed, such that the tissue-removing element **16** engages a peripheral portion of the body lumen BL that is about 30 degrees offset, in the clockwise direction, from the peripheral portion of the body lumen of the first tissue-removing pass, and the user makes the second tissue-removing pass. Subsequent tissue-removing passes may be made in the same fashion.

As disclosed above, in other embodiments the catheter **12** includes the angular-positioning mechanism **60**, but does not include an angular-displacement sensor **87**. Instead, the user may determine the angular tissue-removing position of the tissue-removing element **16** solely through fluorescence or other imaging means. This catheter **12** has the benefit of allowing the user to automatically (i.e., non-manually) adjust the angular tissue-removing position of the tissue-removing element **16**. Moreover, as shown in FIG. **15**, because the angular-positioning mechanism **60** (e.g., the angular-positioning motor) is within the first three-quarter length L**3** of the catheter body **12** (e.g., adjacent the apposition member), the torsional load applied by the angular-positioning mechanism is not applied along the full length L of the catheter body **12**, thereby making it more likely that the torsional force will be imparted substantially entirely along the length of the first (distal) longitudinal body portion **46** (i.e., rotation of the first (distal) longitudinal body portion, and thus the apposition member, is substantially commensurate with rotation of the prime mover), rather than a portion or all of the torsional load being stored within the first (distal) longitudinal body portion (known as "lag") and possibly released at a later time (known as "whip"). For example, where the angular-positioning motor **60** and the first (distal) longitudinal body portion **46** have a 1:1 ratio (i.e., 1 revolution of the motor equals 1 revolution of the first (distal) longitudinal body portion and the apposition member) torsional load, it may be more likely that rotational of motor degrees imparts 30 degrees of rotation to both the first (distal) longitudinal body portion and the apposition member **52** about the rotational axis A**2** than if the torsional load was applied at the proximal end **12***a* of the catheter body **12**.

As also disclosed above, in other embodiments the catheter **10** includes the angular-displacement sensor **87**, but does not include the angular-positioning mechanism **60**. In such an embodiment, the angular tissue-removing position of the tissue-removing element **87** may be adjusted in the body lumen BL in a conventional manner, such as by rotating or torquing the proximal end **12***a* of the catheter body **12** outside the body of the patient. The user receives feedback as to the angular tissue-removing position of the tissue-removing element **16** through the display **96** or in other communication means, such as other audio, visual, or tactile ways. The catheter **10** including the angular-displacement sensor **87** has the benefit of facilitating more accurate and precise tissue removal because the user has the ability to receive real-time feedback regarding the angular tissue-removing position of the tissue-removing element **16** as the catheter is removing tissue from the body lumen BL. For example, as described above, the user may be able to determine if the distal end **12***b* of the catheter body **12** is "guttering" and then make necessary adjustments to the catheter **10**, as described above.

In another embodiment, the control circuit **94** (or another control circuit) of the catheter **10** may be electrically connected to (i.e., in communication with) both the angular-positioning motor **60**, for controlling operation of the motor, and the angular-displacement sensor **87**, for receiving feedback as to the angular tissue-removing position of the tissue-removing element **16**. Accordingly, as opposed to the first embodiment where the user directly controls the operation of the angular-positioning motor **60**, in this embodiment the user inputs the desired (i.e., inputted) angular tissue-removing position of the tissue-removing element **16** to the control circuit **94**, and the control circuit controls the angular-positioning motor to move the tissue-removing element **16** to the desired angular tissue-removing position. Unless otherwise indicated, the present embodiment of the catheter is identical to the first embodiment, with like components being indicated by corresponding reference numerals, and the same teachings set forth with respect to the first embodiment apply equally to the present embodiment.

FIG. **16** illustrates an exemplary block diagram of the present embodiment, showing electrical components of the catheter **10** in communication with the control circuit **94**. In this example, the control circuit **94** receives respective input signals from the following components: the power source **21** for regulating electrical power to the angular-positioning motor **60**; the angular-displacement sensor **87** to determine the contemporaneous angular tissue-removing position of the tissue-removing element **16**; and a user input **98** for allowing a user to input the desired angular tissue-removing position of the tissue-removing element to the control circuit **94**. The power source **21** may be the same power source electrically connected to the driveshaft motor **30** (e.g., a battery in the handle), or a different power source. The angular position sensor **87** may be the same as described above, such as a gyroscope, and as illustrated in FIGS. **2** and **12**. The control circuit **94** sends respective output signals to the following components: the contemporaneous angle display **96** for displaying the contemporaneous angular tissue-removing position of the tissue-removing element **16**; the desired angle display **104** for displaying the desired tissue-removing position of the tissue-removing element; and an H-bridge **100** for enabling a voltage to be applied across the angular-positioning motor **60** in either direction to selectively drive the motor in the clockwise direction and the counterclockwise direction.

Referring to FIG. **17**, one embodiment of a handle (or control unit), including some of the electrical components shown in FIG. **16**, is generally indicated at **14'**. Unless otherwise indicated, the present embodiment of the handle **14'** is identical to the first handle **14**, with like components being indicated by corresponding reference numerals, and the same teachings set forth with respect to the first embodiment apply equally to the present embodiment. Although not illustrated, the control circuit **94**, the power source **21**, the driveshaft motor **30**, and the H-bridge **100** may be provided in the handle **14'**. In the illustrated embodiment, the user input **98** is in the form of a touchscreen display (e.g., an LCD touchscreen) on the handle **14'**. The control circuit **94** is configured to generate graphical icons on the user input display **98**, such as an up arrow (↑) **106**, a down arrow (↓) **108**, and the word "ENTER" **110**, as illustrated, to allow the user to communicate to the control circuit the desired amount of rotation of the tissue-removing element **16** in the body lumen BL. The control circuit **94** is configured to generate graphical image(s) **111** on the contemporaneous angle display **96**, to communicate the contemporaneous angular tissue-removing position of the tissue-removing element **16** to the user, and graphical image(s) **112** on the desired angle display **104**, to communicate the selected desired angular tissue-removing position to the user.

The control circuit **94** and the user input **98** are configured so that the user touches a respective one of the up and down arrows **106**, **108**, respectively, generated on the display to communicate to the control circuit the magnitude and direction that the user desires to change the angular tissue-removing position of the tissue-removing element **16**. In the illustrated embodiment, the up arrow **106** indicates a change in angular position in the clockwise direction, and the down arrow **108** indicates a change in angular position in the counterclockwise direction. In one embodiment, the number of discrete times the selected arrow **106**, **108** is touched and/or the amount of time the selected arrow is continuously touched, communicates a selected the magnitude to the control circuit **94** to change the angular tissue-removing position of the tissue-removing element **16** in the selected direction. This magnitude is stored in the memory and the control circuit **94** changes the graphical image **112** on the desired angular position display **104** to reflect the adjustment. In the illustrated embodiment, a positive graphical symbol ("+") indicates angular displacement of the tissue-removing element **16** in the clockwise direction relative to a reference angular position, and a negative graphical symbol ("−") indicates angular displacement in the counterclockwise direction relative to a reference angular position.

When the desired angle is presented on the display **96** (as represented by the graphical number "+30" in FIG. **17**), the user may touch the "ENTER" icon to thereby instruct the control circuit **94** to move the tissue-removing element **16** to angular tissue-removing position presented on the display **104**, which is also stored in memory. The control circuit **94** communicates with the angular-positioning motor **60** to adjust the tissue-removing element **16**. The display **96**, which may be similar or identical to the corresponding display of the prior handle embodiment, outputs the contemporaneous angular tissue-removing position of the tissue-removing element **16**, as computed by the control circuit **94** using signals from the angular position sensor **87**. The control circuit **94** may use the signals from the angular position sensor **87** as feedback for positioning the tissue-removing element. In another example, the control circuit **94** may be configured to adjust the angular tissue-removing position of the tissue-removing element **16** in other ways. For example, the control circuit **94** may be configured (e.g., programmed) to supply the angular-positioning motor **60** with a pre-selected amount of power for a pre-selected amount of time to adjust the tissue-removing element **16** to the desired (i.e., inputted) angular tissue-removing position.

Because the control circuit **94** controls the angular tissue-removing position of the tissue-removing element **16**, in one or more embodiments the control circuit may be configured to maintain the tissue-removing element **16** in substantially the desired (i.e., inputted) angular tissue-removing position, as the user is making a tissue-removing pass in the body lumen BL. In this embodiment, the control circuit **94** uses the signals from the angular position sensor **87** as feedback for maintaining the tissue-removing element in its selected angular tissue-removing position in the body lumen BL. This embodiment is meant to counteract the tendency of distal end **12***b* of the catheter body **12** to gutter during a tissue-removing pass and inhibit the tissue-removing element **16** from deviating from the desired and selected angular position of the tissue-removing pass.

In one embodiment, the catheter **10** may be configured to restrict or limit the amount of rotation of the apposition member **52** and the first (distal) longitudinal body portion **46** about the rotation axis A**2**. For example, the control circuit **94** may be programmed to inhibit the user from rotating beyond about 360 degrees. That is, the control circuit **94** may be programmed to use the signals from the angular position sensor **87** as feedback and inhibit the user from increasing the angular position of the tissue-removing element beyond about 360 degrees from the initial reference position. The catheter **10** may also include an indicator, such as a visual indicator (e.g., and LED), audio indicator, or tactile indicator, on the handle **14'** to communicate to the user that the tissue-removing element **16** has reached a maximum allowable angular displacement and further rotation of the tissue-removing element **16** in the same direction is inhibited. Without restricting the amount of rotation of the first (distal) longitudinal body portion **46**, a guidewire (not shown) may wrap around and become tangled with the catheter body **12**. Moreover, the rotating the apposition member **52** and the first (distal) longitudinal body portion **46** more than 360 degrees may place undue tension on the electrical conductors **92** (e.g., wires) connecting the sensor **87** to the handle **14**, which may damage the connections between the conductors and the sensor and the handle. Other ways of restricting rotation of the apposition member **52** and the first (distal) longitudinal body portion **46** about the rotation axis A2 do not depart from the scope of the present invention. In one example, the catheter **10** may include a mechanical stop, such as a stop adjacent the prime mover **60**, for inhibiting the prime mover from rotating more than about 360 degrees.

Although the control circuit **94** is illustrated as a single, integrated circuit throughout the drawings and the above-described embodiments, it is understood that the control circuit may include separate, individual control circuits (e.g., separate microcontrollers), each dedicated to one of the prime mover and the angular-displacement sensor.

Having described the invention in detail, it will be apparent that modifications and variations are possible without departing from the scope of the invention defined in the appended claims.

When introducing elements of the present invention or the preferred embodiment(s) thereof, the articles "a", "an", "the" and "said" are intended to mean that there are one or more of the elements. The terms "comprising", "including" and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

As various changes could be made in the above constructions, products, and methods without departing from the scope of the invention, it is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A tissue-removing catheter for removing tissue from a body lumen having a longitudinal axis, the tissue-removing catheter comprising:

a catheter body configured for insertion in the body lumen, the catheter having a proximal end, a distal end, and a longitudinal axis extending between the proximal and distal ends, wherein at least a first longitudinal body portion of the catheter body is rotatable about a rotational axis extending along the length of the catheter body;

a tissue-removing element coupled to the first longitudinal body portion of the catheter body, wherein the tissue-removing element is configured to rotate with the first longitudinal body portion about the rotational axis; and

an angular-displacement sensor coupled to the first longitudinal portion of the catheter body, wherein the angular-displacement sensor is configured to rotate with the first longitudinal body portion and the tissue-removing element about the rotational axis and configured to detect an angular displacement of at least said first longitudinal body portion of the catheter body and said tissue-removing element relative to the rotational axis when the first longitudinal body portion is rotated about the rotational axis;

a control circuit connectable to the angular-displacement sensor, wherein the control circuit is configured to:

receive electrical signals from the angular-displacement sensor indicative of an angular displacement of the first longitudinal body portion of the catheter body relative to a reference angular position of the first longitudinal body portion of the catheter body; and

compute the angular displacement of the first longitudinal body portion using the received electrical signals from the angular-displacement sensor; and

a control unit connectable to the catheter body, the control unit comprising the control circuit, and a display electrically connected to the control circuit, wherein the control circuit is configured to display the computed angular displacement of the first longitudinal body portion as an angle on the display.

2. The tissue-removing catheter set forth in claim **1**, wherein the angular-displacement sensor comprises a gyroscope.

3. The tissue-removing catheter set forth in claim **1**, further comprising:

at least one electrical conductor electrically connected to the angular-displacement sensor and electrically connectable to the control circuit for receiving electrical signals from the angular-displacement sensor indicative of the angular displacement of at least said first longitudinal body portion of the catheter body relative to the rotational axis when the tissue-removing element is rotated about the rotational axis.

4. The tissue-removing catheter set forth in claim **1**, wherein the catheter body includes a second longitudinal body portion proximal of the first longitudinal body portion, the first longitudinal body portion being rotatable along its length relative to the second longitudinal body portion to adjust the angular position of the first longitudinal body portion relative to the second longitudinal body portion.

5. The tissue-removing catheter set forth in claim **4**, further comprising an angular-positioning mechanism operatively connected to the first longitudinal body portion and configured to rotate the first longitudinal body portion along its length and relative to the second longitudinal body portion to adjust the angular position of the first longitudinal body portion relative to the second longitudinal body portion.

6. The tissue-removing catheter set forth in claim **5**, wherein the angular-positioning mechanism comprises a prime mover, the control circuit being operatively connectable to the prime mover for controlling operation of the prime mover for imparting rotation to the first longitudinal body portion relative to the second longitudinal body portion of the catheter body.

7. The tissue-removing catheter set forth in claim **6**, wherein the control unit comprises a user input electrically connected to the control circuit for instructing the control circuit to rotate the first longitudinal body portion to a selected angular position relative to the reference angular position.

8. A tissue-removing catheter for removing tissue from a body lumen having a longitudinal axis, the tissue-removing catheter comprising:

a catheter body configured for insertion in a body lumen of a subject, the catheter having a proximal end, a distal end, a longitudinal axis extending between the proximal and distal ends;

a tissue-removing element coupled to the catheter body and configured to be positioned in an angular tissue-removing position relative to the longitudinal axis of the body lumen when the catheter body is inserted in the body lumen, the tissue-removing element being rotatable about a rotational axis to adjust an angular tissue-removing position of the tissue-removing element relative to the longitudinal axis of the body lumen when the catheter body is inserted in the body lumen;

an angular-displacement sensor generally adjacent the tissue-removing element, the angular-displacement sensor configured to detect an angular displacement of the tissue-removing element relative to the longitudinal axis of the body lumen when the tissue-removing element is rotated about the rotational axis;

a control circuit connectable to the angular-displacement sensor, wherein the control circuit is configured to:

receive electrical signals from the angular-displacement sensor indicative of an angular displacement of the tissue-removing element relative to a reference angular position of the tissue-removing element; and

compute the angular displacement of the tissue-removing element using the received electrical signals from the angular-displacement sensor; and

a control unit connectable to the catheter body, the control unit comprising the control circuit, and a display electrically connected to the control circuit, wherein the control circuit is configured to display the computed angular displacement of the tissue-removing element as an angle on the display.

9. The tissue-removing catheter set forth in claim **8**, wherein the angular-displacement sensor is configured to rotate with the tissue-removing element about the rotational axis.

10. The tissue-removing catheter set forth in claim **9**, wherein the angular-displacement sensor comprises a gyroscope.

11. The tissue-removing catheter set forth in claim **8**, further comprising:

at least one electrical conductor electrically connected to the angular-displacement sensor and electrically connectable to the control circuit for receiving electrical signals from the angular-displacement sensor indicative of the angular displacement of the tissue-removing element relative to the rotational axis.

12. The tissue-removing catheter set forth in claim **8**, wherein the catheter body includes a first longitudinal body portion and a second longitudinal body portion proximal of the first longitudinal body portion, the first longitudinal body portion being rotatable along its length relative to the second longitudinal body portion to adjust the angular position of the first longitudinal body portion relative to the second longitudinal body portion,

wherein the tissue-removing element is coupled to the first longitudinal body portion such that the tissue-removing element rotates with the first longitudinal body portion.

13. The tissue-removing catheter set forth in claim **12**, further comprising an angular-positioning mechanism operatively connected to the first longitudinal body portion and configured to rotate the first longitudinal body portion along its length and relative to the second longitudinal body portion to adjust the angular position of the first longitudinal body portion relative to the second longitudinal body portion.

14. The tissue-removing catheter set forth in claim **13**, wherein the angular-positioning mechanism comprises a prime mover, the control circuit being operatively connectable to the prime mover for controlling operation of the prime mover for imparting rotation to the first longitudinal body portion relative to the second longitudinal body portion.

15. The tissue-removing catheter set forth in claim **14**, wherein the control unit comprises a user input electrically connected to the control circuit for instructing the control circuit to rotate the first longitudinal body portion to a selected angular position relative to a reference angular position.

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